
Performance-Oriented Logistics Assessment (POLA)

Executive Summary

James H. Bigelow

DISTRIBUTION STATEMENT A:
Approved for Public Release -
Distribution Unlimited

20041208 055

The research described in this report was sponsored by the United States Army, Contract No. MDA903-91-C-0006.

Library of Congress Cataloging in Publication Data

Bigelow, J. H.

Performance oriented logistics assessment (POLA). Executive summary / James H. Bigelow ; prepared for the United States Army.

p. cm.

Includes bibliographical references (p.).

"R-3823-A."

ISBN 0-8330-1187-1

1. United States. Army—Equipment—Maintenance and repair—Computer simulation. 2. Armed Forces—Equipment—Maintenance and repair—Computer simulation. 3. North Atlantic Treaty Organization—Armed Forces—Equipment—Maintenance and repair—Computer simulation.

I. United States. Army. II. RAND Corporation. III. Title.

UC263.B53 1992

355.8'028'8—dc20

91-29715

CIP

RAND is a nonprofit institution that seeks to improve public policy through research and analysis. Publications of RAND do not necessarily reflect the opinions or policies of the sponsors of RAND research.

R-3823-A

Performance-Oriented Logistics Assessment (POLA)

Executive Summary

James H. Bigelow

Prepared for the
United States Army

RAND

PREFACE

This document is one of four describing the Performance-Oriented Logistics Assessment (POLA) Project. The three companion documents are:

- *Performance-Oriented Logistics Assessment (POLA): Users' Manual for the Logistics Decision Model (LDM), Version IV*, R-3814-A, which explains the mechanics of using LDM, a personal computer (PC)-based theater campaign simulation model that plays a central role in the POLA methodology;
- *Performance-Oriented Logistics Assessment (POLA): Preparing the Logistics Decision Model (LDM) for Use in Analyses*, N-3393-A, which explains how to calibrate LDM and how to build its input files; and
- *Performance-Oriented Logistics Assessment (POLA): Relating Logistics Functional Capacities to Resources and Costs*, N-3354-A, which discusses in some detail other parts of the methodology.

POLA was a project in RAND's Arroyo Center, sponsored by the Deputy Chief of Staff, Logistics (DCSLOG) Directorate of Plans and Operations (DALO-PLA). Its purpose was to develop a prototype methodology to help build the logistics portion of the Army five-year program.

By "prototype methodology," we mean a methodology that has been developed to the point that its usefulness has been demonstrated. That has been done: the Logistics Evaluation Agency (LEA) has adopted the prototype methodology, built a "shell" to link it with existing Army data files (such as the Total Army Equipment Distribution Program, or TAEDP), and is using the combined system on real Army logistics problems. The agency calls the combined system Logistics Net Assessment (LNA). LNA is not yet a polished, user-friendly, fully supported system. Nor does it deal with all the logistics resources it might. Support of LNA and its further development (which appears to be worthwhile) is the responsibility of the Army.

This executive summary briefly reviews the POLA methodology and its uses. For those who will be only consumers of results from analyses that use the methodology, this overview may be sufficient. For

those who will need to use the methodology themselves, this overview will serve as an introduction to the three companion volumes.

THE ARROYO CENTER

The Arroyo Center is the U.S. Army's federally funded research and development center (FFRDC) for studies and analysis operated by RAND. The Arroyo Center provides the Army with objective, independent analytic research on major policy and organizational concerns, emphasizing mid- and long-term problems. Its research is carried out in four programs: Strategy and Doctrine, Force Development and Technology, Military Logistics, and Manpower and Training.

Army Regulation 5-21 contains basic policy for the conduct of the Arroyo Center. The Army provides continuing guidance and oversight through the Arroyo Center Policy Committee (ACPC), which is co-chaired by the Vice Chief of Staff and by the Assistant Secretary for Research, Development, and Acquisition. Arroyo Center work is performed under contract MDA903-91-C-0006.

The Arroyo Center is housed in RAND's Army Research Division. RAND is a private, nonprofit institution that conducts analytic research on a wide range of public policy matters affecting the nation's security and welfare.

Lynn E. Davis is Vice President for the Army Research Division and Director of the Arroyo Center. Those interested in further information about the Arroyo Center should contact her office directly:

Lynn E. Davis
RAND
1700 Main Street
P.O. Box 2138
Santa Monica CA 90407-2138

SUMMARY

INTRODUCTION

Performance-Oriented Logistics Assessment (POLA), a project sponsored by the Army Deputy Chief of Staff, Logistics (DCSLOG) Directorate of Plans and Operations (DALO-PLA), has developed a prototype methodology to help build the logistics portion of the Army five-year program. The POLA methodology estimates both the costs and the effects on combat performance of alternative logistics improvements. By comparing their costs and effects on combat performance, one can arrive at a balanced program that provides greater combat effectiveness for each logistics dollar spent.

THE POLA METHODOLOGY

The POLA methodology consists of several small models, as shown in Fig. S.1. The Logistics Decision Model (LDM) estimates combat performance measures (e.g., forward line of troops (FLOT) movement and attrition) from resources on hand in the theater¹ (e.g., tanks, tank crews, ammunition) and capacities available to perform logistics functions (e.g., maintenance, ammunition distribution). Before LDM can be used for analysis, it must be calibrated² and provided with a description of the theater support system. During an analysis, a user can vary capacities and quantities of resources and observe the effects of these variations on combat performance measures.

¹So far, LDM has been used to simulate only the NATO theater, but given the appropriate data, I see no reason the model could not be used equally well for other theaters.

² To date, I have calibrated LDM to cases generated by the Concepts Evaluation Model (CEM) and Force Evaluation Model (FORCEM). CEM is a large theater simulation model used by the U.S. Army Concepts Analysis Agency (CAA) in a variety of studies that provide requirements information for building the Army five-year program. FORCEM, a model in the late stages of development at CAA, is intended to replace CEM. Because CEM's (and soon FORCEM's) intended use overlaps that of the POLA methodology, I designed LDM to produce results consistent with those models. However, I see no reason that LDM could not be calibrated with equal success to other theater- or corps-level combat simulation models.

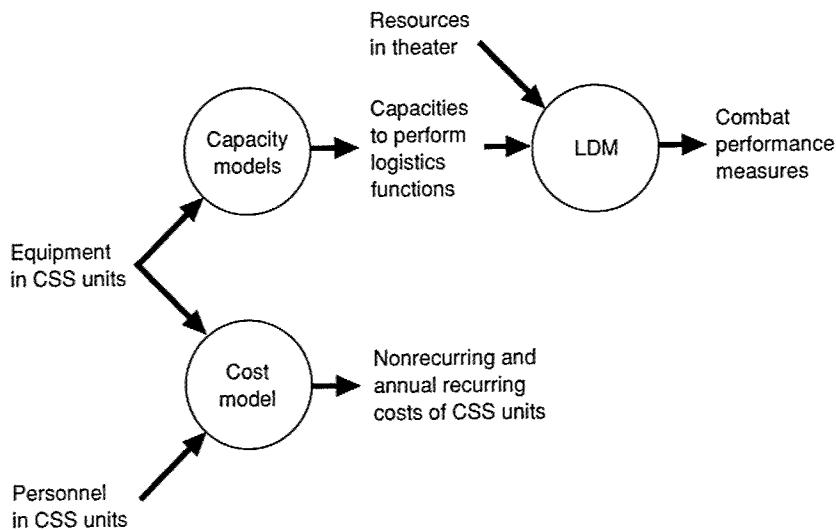


Fig. S.1—Overview of the POLA Methodology

Capacity models estimate the capacities needed by LDM from the equipment on hand in the Combat Service Support (CSS) units (e.g., General Support (GS) Ordnance Companies) that perform logistics functions. These models build upon a general method borrowed from AR 220-1, *Unit Status Reporting*, and tailor it to suit each specific kind of unit.

The cost model estimates the cost of increasing those capacities by adding or replacing equipment in those CSS units. It separately estimates nonrecurring costs (e.g., initial procurement of spares and repair parts, initial training of personnel) and annual recurring costs (e.g., replenishment spares and repair parts, military pay and allowances, a share of depot maintenance costs). To estimate the incremental cost of improvements to CSS units, one applies the model before a unit receives a logistics improvement and again afterward. The cost of the improvement is the difference between the “before” and “after” cost estimates.

The methodology is particularly designed to assess logistics improvements that add capacity to perform logistics functions (e.g., ammunition distribution) to the theater support system by adding or replacing equipment in CSS units. It can also assess logistics improvements that add capacity by adding entire new CSS units,

stocks of ammunition, war reserve equipment, or other resources. The methodology can assess the effects on combat performance of reducing the capacity to perform a logistics function, although estimating the resulting savings presents problems.

A full analysis would investigate many possible logistics improvements or reductions and would require considering hundreds of cases. I have therefore designed the methodology to be very fast (minutes per case), highly aggregate (to reduce the difficulty of preparing inputs), and very small (to fit on the personal computers the Army is making readily available).

AN ILLUSTRATIVE ANALYSIS

With the LDM program I distribute a test case in which the ammunition-handling capacity at a particular echelon is frequently exhausted, without meeting the full demand for ammunition. For an illustrative analysis, I select six cases in which ammunition-handling capacity is varied from the capacity in the test case of 28,800 tons per day, as shown in Table S.1. I will suppose that this capacity is supplied by GS Ordnance Companies, whose capacities can be increased by adding fork lifts and cranes (the critical equipment items). Capacity is reduced by eliminating companies.

Figure S.2 gives examples of the effect on combat performance of these changes in ammunition-handling capacity, as estimated using LDM. Increases in ammunition-handling capacity above the base case (Case 4) appear to be of little combat value, since they affect neither Blue attrition nor the cumulative distance that Blue retreats. However, decreases cause Blue to lose ground to Red. Decreases also cause Blue to withhold weapons from combat and therefore to suffer fewer losses. The user must decide whether loss of territory outweighs the decrease in attrition.

Figure S.3 shows the nonrecurring and annual recurring costs for the six cases, plotted against the total ammunition-handling capacity. For the excursion cases that add capacity (Cases 5 and 6), the costs are the difference between the costs of creating and maintaining the units at the two different capacities. For the cases that reduce capacity (Cases 1, 2, and 3), the Army cannot recover the nonrecurring cost. The amount of the recurring cost they save will depend on how many people and how much equipment they retain from the eliminated units. Presumably, they would also derive some benefit from resources they retained. To make the analysis complete, one should

Table S.1

**Ammunition-Handling Capacities
for the Six Cases in the
Illustrative Analysis
(tons/day)**

Case	Tons/Day
1	0
2	8640
3	17280
(Base) 4	28800
5	39412
6	51464

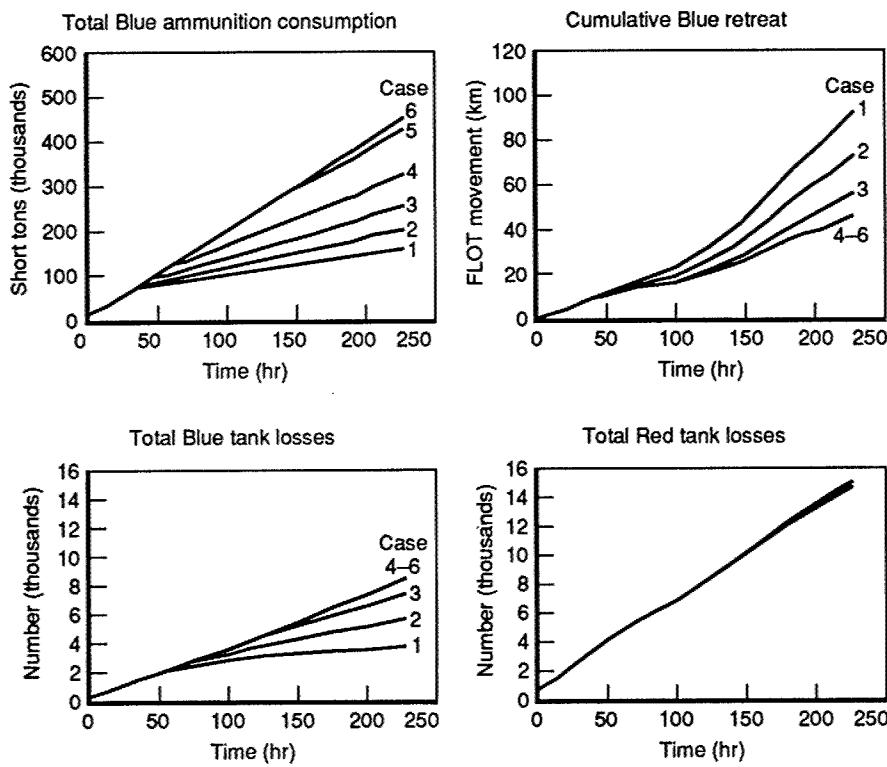


Fig. S.2—Results from the Six Analysis Cases

specify the disposition of personnel and equipment from the eliminated units, and estimate their costs and benefits in their new roles.

LOGISTICS NET ASSESSMENT

The methodology developed by the POLA project has been adopted by the U.S. Army Logistics Evaluation Agency (LEA). The Operations Research and Systems Analysis (ORSA) Support Team at LEA is responsible for further development and implementation of methodology, for maintaining data files, and for periodically recalibrating LDM. They have created a Logistics Net Assessment (LNA) system that incorporates LDM and selected capacity models (but as of this writing, not the cost model). They can provide the LNA package to action officers in the Pentagon, each of whom can then perform his own mini-analyses for the resources he is responsible for. The ORSA Support Team can also perform its own more complete analyses.

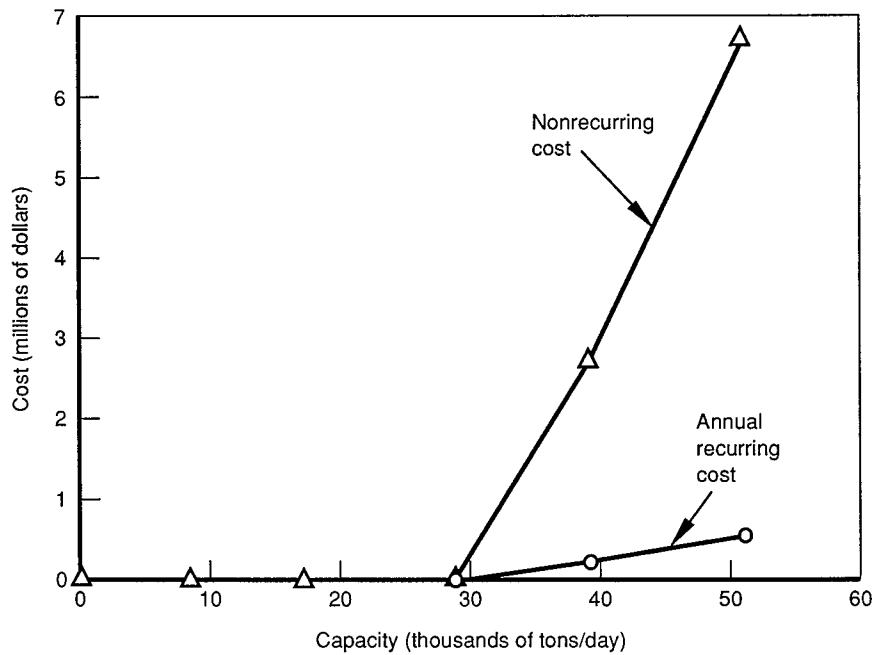


Fig. S.3—Cost Versus Capacity for the Six Analysis Cases

ACKNOWLEDGMENTS

The author is grateful to the following people for their contributions.

- The ORSA Support Team at the Logistics Evaluation Agency (LEA) uncovered errors and suggested numerous improvements in early versions of the POLA methodology. The team has incorporated the latest versions of the models in their Logistics Net Assessment system.
- Richard Kaplan and Raymond Pyles of RAND reviewed an early draft of this Report and made helpful suggestions for its improvement.
- Irene Gordon prepared the manuscript for publication.

CONTENTS

PREFACE	iii
SUMMARY.....	v
ACKNOWLEDGMENTS	xi
FIGURES AND TABLES	xv
Section	
1. INTRODUCTION	1
2. THE POLA METHODOLOGY	3
The Logistics Decision Model	3
POLA's Capacity Models.....	5
POLA's Cost Model	6
3. PREPARING DATA FOR A BASE CASE	8
Calibration	8
Representing the Theater Support Structure	9
Determining Inventories of CSS Units Entering the Theater.....	11
4. AN ILLUSTRATIVE ANALYSIS	13
Defining Excursion Cases	14
Estimating Effects on Combat Performance	15
Estimating Costs of Logistics Changes	18
5. LOGISTICS NET ASSESSMENT (LNA)	21
REFERENCES	23

FIGURES

S.1.	Overview of the POLA Methodology	vi
S.2.	Results from the Six Analysis Cases	viii
S.3.	Cost Versus Capacity for the Six Analysis Cases	ix
1.	Overview of the POLA Methodology	4
2.	The Logistics Decision Model	5
3.	Ammunition Distribution in the Theater Concept	10
4.	Results from the Six Analysis Cases	17
5.	Cost Versus Capacity for the Six Analysis Cases	20

TABLES

S.1.	Ammunition-Handling Capacities for the Six Cases in the Illustrative Analysis (tons/day)	viii
1.	Ammunition-Handling Capacity over Time in the Test Case	14
2.	Critical Equipment Items for the GS Ordnance Company	16
3.	Ammunition-Handling Capacities over Time for Six Cases in the Illustrative Analysis (tons/day)	16
4.	Cost Model Inputs and Outputs for GS Ordnance Companies with Different Capacities	19

1. INTRODUCTION

When building its five-year program, the Army first estimates a requirement for each resource, but the price of satisfying all requirements always greatly exceeds the amount the Army can spend. Thus, the Army must next decide how much of each requirement not to satisfy. Necessarily, the Army has always made these decisions, but on somewhat arbitrary grounds, because the Army has never succeeded in developing tools that would systematically and auditably rate different resources intended to support disparate functions, on common scales. Performance-Oriented Logistics Assessment (POLA), a project sponsored by the Army Deputy Chief of Staff, Logistics (DCSLOG) Directorate of Plans and Operations (DALO-PLA), has developed a prototype methodology to help build the logistics portion of the Army five-year program.

The POLA methodology estimates both the costs and the effects on combat performance of alternative investments in logistics resources. Combat performance measures thus become the common scales on which different resources are rated. If an increment of one resource has relatively little effect on combat performance and an equal-cost increment of a second resource has a large effect, the Army may prefer to satisfy less of the requirement for the first resource and more of the requirement for the second. Combat performance is measured in terms of forward line of troops (FLOT) movement, Red and Blue weapons engaged and attrited on both sides, and Red and Blue resources consumed and personnel lost. Logistics resources considered include stocks of ammunition, petroleum, oil, and lubricants (POL), war reserve equipment, and replacement personnel. Resources can also be equipment used in Combat Service Support (CSS) units that perform specific logistics functions, such as ammunition handling or transportation of dry cargo.

To evaluate the effect of a resource increment on cost and combat performance, one must generate at least two cases with the POLA methodology: a base case and an excursion in which the resource in question has been increased or decreased. Because there are many resources to be considered, hundreds of cases might be generated by the POLA methodology during the building of an Army program. I have therefore designed the methodology to be very fast (minutes per case), to be highly aggregate (to reduce the difficulty of preparing in-

puts), and to be small (to fit on the personal computers the Army is making readily available).

Section 2 discusses the POLA methodology—the Logistics Decision Model (LDM), the capacity models, and the cost model. Section 3 examines data preparation for analysis, and Sec. 4 presents an illustrative example. Section 5 discusses the adoption of the POLA methodology by the U.S. Army Logistics Evaluation Agency (LEA).

2. THE POLA METHODOLOGY

The POLA methodology consists of several small models, as shown in Fig. 1. The *Logistics Decision Model* (LDM) estimates combat performance measures (e.g., FLOT movement and attrition) from resources on hand in the theater (e.g., tanks, tank crews, ammunition) and capacities available to perform logistics functions (e.g., maintenance, ammunition distribution). *Capacity models* estimate those capacities from the equipment on hand in the CSS units that perform logistics functions (e.g., General Support (GS) Ordnance Companies). The *cost model* estimates the cost of increasing those capacities by adding or replacing equipment in those CSS units.

THE LOGISTICS DECISION MODEL

The Logistics Decision Model is a highly aggregate, two-sided, deterministic¹ simulation of a theater campaign.² A thorough description of LDM can be found in Refs. 1 and 2. It is shown schematically in Fig. 2.

Before LDM can be used for analysis, it must be calibrated to properly represent combat, and it must be provided with a representation of the theater support structure. The combat representation determines how the numbers of different weapon systems (e.g., tanks, artillery) engaged on each side affect combat performance measures (e.g., FLOT movement, Red and Blue weapons attrited, ammunition and POL consumed).

The support structure representation describes how logistics functions such as ammunition distribution and maintenance affect the numbers of weapon systems available over time to engage in combat. Each logistics function is described as a collection of activities such as direct support (DS) repair of tanks at the Division Support Command (DISCOM) or transportation of artillery ammunition from the Corps Storage Area (CSA) to an Ammunition Transfer Point (ATP). These activities may consume, produce, repair, move, or otherwise change the status of the resources (e.g., ammunition, POL, tanks, tank

¹That is, it has no random (Monte Carlo) elements.

²So far, LDM has been used to simulate only the NATO theater, but given the appropriate data, I see no reason the model could not be used equally well for other theaters.

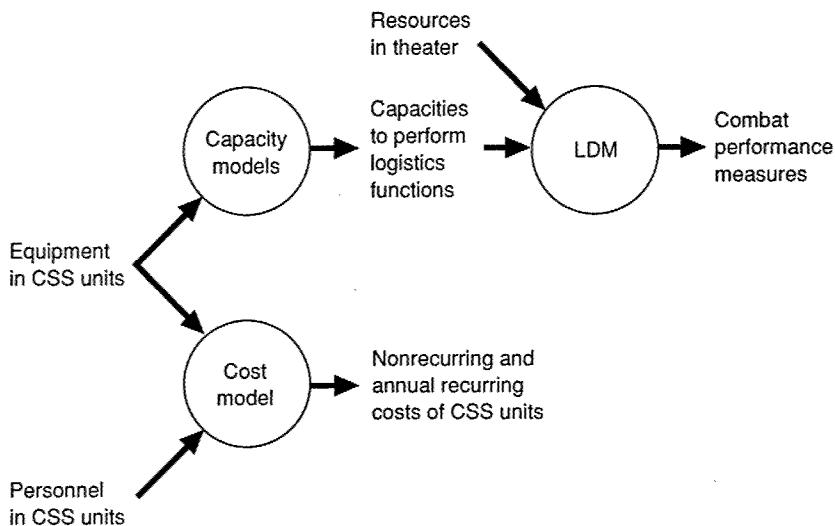


Fig. 1—Overview of the POLA Methodology

crews). CSS units are represented as upper bounds, or capacities, imposed on activities or groups of activities (e.g., the capacity in tons per day to move ammunition of all types from the CSA to the ATP).

During an analysis, a user can vary capacities and quantities of resources, and observe the effects of these variations on combat performance measures. Monitoring the effects on indicators of logistics "health," such as the buildup of queues (e.g., equipment awaiting maintenance, supplies awaiting transportation) or unused capacities may help the user decide what resources or capacities to vary in succeeding cases.

The model has been designed to operate on an IBM-compatible personal computer (PC). It is fast enough (perhaps ten minutes per case, depending on the size of the problem and the speed of the PC) that many variations on a campaign can be simulated at a single sitting. It is written in RM/FORTRAN, Version 2.4. The compiled program occupies about 380 kilobytes of memory and, hence, will run comfortably on a PC with 512 kilobytes of memory. The PC should have either two floppy disk drives or (preferably) one floppy and one hard disk.

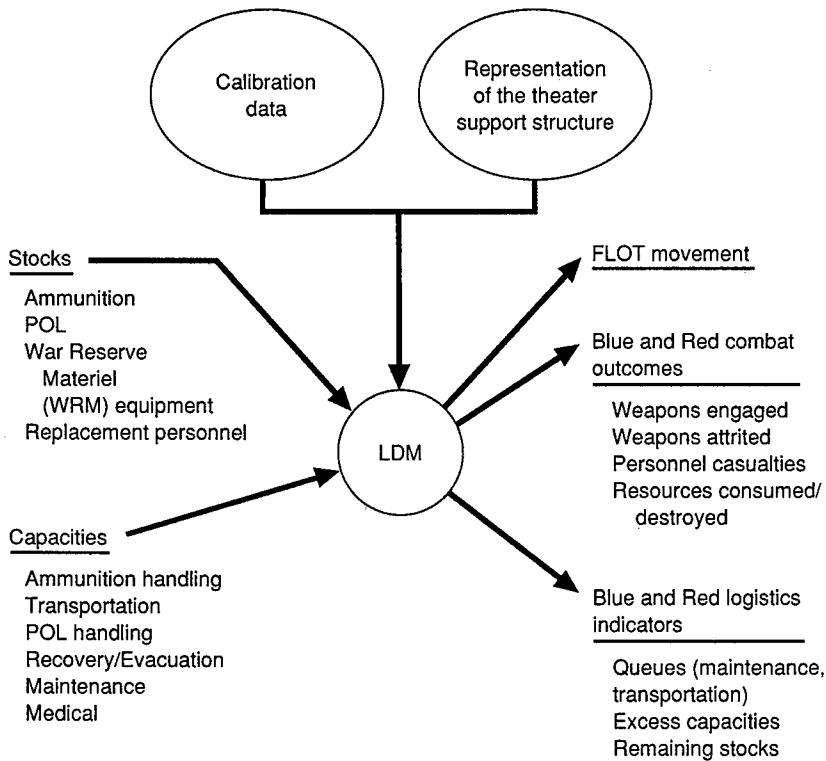


Fig. 2—The Logistics Decision Model

POLA'S CAPACITY MODELS

POLA's capacity models estimate how a unit's capacity depends on the inventories of equipment on hand [3]. In the most general case, the capacity of a CSS unit to perform its primary task will depend not only on the equipment items on hand, but also on the equipment status, the personnel on hand and their status, and environmental factors such as enemy action and support from friendly forces. In POLA, however, I have not considered the effects of environmental factors. In addition, I have assumed that by the time the unit deploys, its complement of personnel has been rounded out and fully trained and that all available equipment has been brought to operational status.

The basic method is adapted from AR 220-1 [4]. First, one must identify the equipment items that are critical for performing the unit's primary task. AR 220-1 identifies items with an Equipment

Readiness Code (ERC) of A or P³ as critical. However, sometimes this list can be improved based on advice from persons with experience in the particular kind of unit. For each critical item, the method forms the ratio of the on-hand to the required quantities. Then it calculates the unit's capacity as the minimum of the ratios, multiplied by the capacity it is designed to have when all its personnel and equipment requirements are filled. This is a simplification of the method discussed in AR 220-1, which allows one to disregard the 10 percent of the ERC A items with the lowest ratios.

The basic method must often be adapted to account for circumstances such as the following. A unit may need night-vision goggles for night-time operations but not for operations in daylight. Thus, night-vision goggles contribute to at most half of the capacity. Alternatively, one equipment item can often be substituted for another, for example, two 10,000 gallon storage bags for a single 20,000 gallon bag. The substitutable items should be combined into "equivalence classes" before the unit's capacity is calculated.

Even with adaptations such as these, the method yields only rough approximations to a unit's capacity. Detailed simulations or actual field exercises would be needed to develop more sophisticated methods (and even then might not yield better approximations). In their absence, however, one must rely on simple approximations.

POLA'S COST MODEL

POLA uses a simple cost model for estimating the costs of logistics improvements to CSS units [3]. It estimates the nonrecurring and annual recurring costs of acquiring, maintaining, and operating an active Army unit⁴ (or collection of units) in peacetime. The model takes as input the procurement cost of the unit's equipment and the numbers of officers, warrant officers, and enlisted personnel. The nonrecurring cost elements it estimates include procurement cost of extra equipment to serve as operational readiness and repair cycle

³The Table of Organization and Equipment (TOE) for a unit contains the ERC code for each equipment item. Equipment items coded ERC A (Primary Weapons and Equipment) are employed directly in the accomplishment of assigned operational missions and tasks. Equipment items coded ERC P (Pacing Items) are items to which the capacity of the unit is particularly sensitive.

The A57 TOE Edit File contains computer-readable listings of all Tables of Organization and Equipment. It is available from Headquarters TRADOC (ATCD-OA), Ft. Monroe, VA 23651.

⁴There is a version of this model for National Guard and Army Reserve units, but the documentation is not in a form that can be distributed.

floats, initial procurement of spares and repair parts for both the unit and central supply, initial training of personnel, and so forth. Annual recurring cost elements include replenishment spares and repair parts, military pay and allowances for the unit's personnel, a share of depot maintenance costs, and the like.

To estimate the incremental cost of improvements to CSS units, one applies the model before a unit (or collection of units) receives a logistics improvement and again afterward. The cost of the improvement is the difference between the "before" and "after" cost estimates. If the improvement consists of replacing old kinds of equipment with new kinds (e.g., an old type of fork lift with a new, more capable one), the nonrecurring cost of the displaced equipment must be treated as "sunk." It cannot be used to offset the costs associated with the new equipment, but it can be transferred to other units.⁵ If possible, costs (as well as benefits) should be estimated for the entire collection of units affected by the improvement, including those that receive the displaced equipment.

A separate "before" versus "after" difference can be calculated for each cost element, and these differences can be summarized and presented in several ways. Sometimes it is useful to present a single cost index that can be used for quick comparisons of alternatives, such as life-cycle cost. This is defined as the total nonrecurring cost plus a specified number of years' worth of the total annual recurring cost. (The Army often uses 20 years.) It would be useful to spread the estimated cost elements over fiscal years to provide estimates of the effect of a proposed logistics improvement on the Army's budget, but the current version of the model does not do so.⁶

⁵The user must redistribute displaced equipment manually, as the methodology contains no tools to do so automatically.

⁶The Arroyo Center has undertaken to produce a version that does assign costs to budget years. It will impose on the user the added burden of specifying a schedule for making the improvement—that is, year by year, how many new equipment items and personnel would be added to the unit, and how many old equipment items and personnel retired.

3. PREPARING DATA FOR A BASE CASE

Before one can perform an analysis with the POLA methodology, one must prepare the necessary data. The analysis will involve applying the methodology to many separate cases and observing differences among them. A complete set of input data files must be prepared for each case, although much of the data will be duplicated from one case to another. One case will be identified as a base case, which serves as a point of departure and comparison for all other cases. For example, if one is analyzing logistics improvements to the U.S. Army in Europe as of 1989, then the capabilities of the weapons, the support structure, and the inventories of resources in the base case should all reflect those of the U.S. Army in Europe as of 1989. All other cases will represent excursions from that situation.

I will discuss the preparation of data for the base case in the next three subsections. The first subsection discusses how LDM is calibrated to represent combat properly. The second subsection outlines how to build a representation of the theater support structure for LDM. The third subsection describes how to determine the numbers and schedules of CSS units entering the theater.

CALIBRATION

Calibrating means adjusting various LDM inputs so the model closely approximates the combat outcomes from a specified reference (or calibration) case. To date, I have calibrated LDM to cases generated by the CEM and FORCEM models. CEM (Concepts Evaluation Model) is a large theater simulation model used by the U.S. Army Concepts Analysis Agency (CAA) in a variety of studies that provide requirements information for building the Army five-year program. FORCEM (Force Evaluation Model), a model in the late stages of development at CAA, is intended to replace CEM. Because CEM's (and soon FORCEM's) intended use overlaps that of the POLA methodology, I designed LDM to produce results consistent with those models.¹

Huge (tens or hundreds of megabytes) input and output data files from either CEM or FORCEM are needed to calibrate LDM. In the

¹It should be possible to calibrate LDM to virtually any other theater model that considers only the close battle. The LDM program would have to be modified to consider deep strikes, whether against infrastructure (e.g., bridges and ports), combat units, or logistics targets.

calibration process, I extract from these huge files such LDM inputs as:

- Time-phased schedules for Blue and Red combat forces and combat resources² to enter the theater;
- Rules governing how much of the Blue and Red forces will be engaged at different local force ratios, as a function of the overall theater force ratio;
- Rules governing how much of the force engaged at a particular local force ratio will be in each of the three engagement types (“Blue Attack-Red Defend” versus “Static” versus “Red Attack-Blue Defend”);
- Attrition of each weapon system, depending on local force ratio and type of engagement;
- FLOT movement rate, also depending on local force ratio and engagement type.

Calibrating LDM is partly science and partly art. I extract LDM inputs from the CEM or FORCEM files, and then compare results from a LDM simulation with the CEM or FORCEM outputs. Initially they will not match, so I judiciously adjust the LDM inputs to converge toward agreement in the outputs. There are numerous indications of what adjustments are likely to yield improvements. For example, if LDM estimates more Blue tank losses than CEM or FORCEM, one might reduce the attrition rates for Blue tanks. But each adjustment causes many simulated results to change, so the adjustment process must be repeated several times.

REPRESENTING THE THEATER SUPPORT STRUCTURE

To build a representation of the theater support structure, I typically identify the various logistics functions I wish to represent, such as the distribution of ammunition or the maintenance and resupply of major items of equipment. For each logistics function, I lay out the function as a network and list the activities that occur at each node and link. Figure 3, for example, shows the Army’s standard concept

²That is, resources used by combat forces. These include combat equipment, combat personnel, ammunition, and so forth. They do not include CSS units. Inventories of CSS units entering the theater are determined in a different data preparation step.

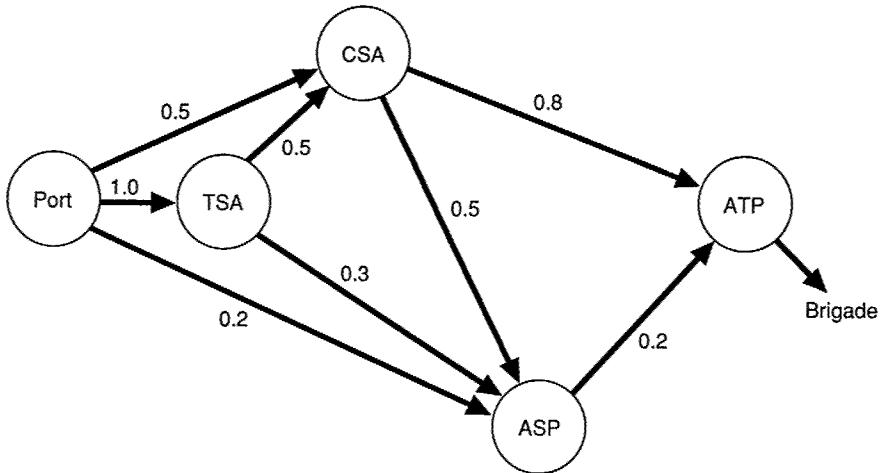


Fig. 3—Ammunition Distribution in the Theater Concept

for ammunition distribution, in network form [5]. Users draw the ammunition they require from the Ammunition Transfer Point (ATP) at the right of the figure. The ATP in turn receives 80 percent of its ammunition from the Corps Storage Area (CSA) and the remaining 20 percent from the Ammunition Supply Point (ASP). (Note the distribution fractions on the network links in Fig. 3.) Half the ASP supply comes from the CSA, whereas 30 percent comes directly from the Theater Storage Area (TSA) and the remainder comes directly from the Port.

Each activity will consume some resources and produce others. For example, moving artillery ammunition from the CSA to the ATP “consumes” ammunition at the CSA and “produces” it at the ATP. Similarly, activities may consume the capacity to perform a logistics function. Moving ammunition, for example, consumes ton-miles of transportation capacity and tons of ammunition-handling capacity. LDM does not allow activities to consume more of a resource or a capacity than is available.

I also define activities that place demands on each logistics function. For the ammunition distribution function, for example, these are the activities that requisition ammunition from the distribution system to replace the ammunition that is consumed. For the major equipment repair and resupply system, these are activities that generate broken

items of equipment to be repaired and activities that requisition operating equipment items to replace those lost.

Finally, I provide consequences for failure to meet the demands placed on the logistics function. For example, I define activities that combine resources in specified proportions to form weapon systems available for combat. Thus, a tank cannot enter combat unless there is a crew available, plus specified amounts of various kinds of ammunition. An ammunition shortage at the brigade echelon may therefore limit the numbers of tanks (and other kinds of weapon systems) available to engage in combat. A shortage of POL may limit not only the available weapon systems, but also the capacity to distribute ammunition and POL itself.

DETERMINING INVENTORIES OF CSS UNITS ENTERING THE THEATER

In building a representation of the theater support structure, I identify the types of units that provide capacities for the modeled logistics functions. The CSS units to be considered in the analysis will be the units of these types that deploy to the theater of operations in the scenario used for the analysis. A useful data source is the "M" Force, an extract from the Force Accounting System (FAS)³ that lists all the units in the Army.

For each unit appearing in the base case, one must determine the inputs needed by both LDM (capacity and arrival date in theater) and the cost model (equipment procurement costs, inventories of personnel). Capacities are estimated from equipment on hand, using capacity models such as those discussed above. Equipment on hand may be taken from the Total Army Equipment Distribution Program (TAEDP).⁴ If the standard Illustrative Planning Scenario is used for the analysis, one of the data elements in the FAS can be used to determine which units will deploy to the theater and when they will do so. For other scenarios, the user must locate his own sources of in-

³The Force Accounting System (FAS) is the responsibility of the DCSOPS Directorate of Operations, Readiness, and Mobilization (DAMO-OD), Pentagon.

⁴The functional proponent of the TAEDP is the DCSLOG Equipment and Readiness Division (DALO-SMD), Pentagon. The files themselves are maintained at Depot Systems Command, Chambersburg, PA 17201.

formation. Prices of equipment items, needed to develop inputs for the cost model, can be found in the Army Master Data File (AMDF).⁵

⁵The Army Master Data File (AMDF) can be obtained from the U.S. Army Materiel Command's Catalogue Data Activity, New Cumberland Army Depot, New Cumberland, PA 17070-5010.

4. AN ILLUSTRATIVE ANALYSIS

In this section, I illustrate how the POLA methodology can be used. The methodology is intended to assess possible logistics improvements by estimating their effects on both combat performance and on costs in peacetime. It is particularly designed to assess logistics improvements accomplished by adding or replacing equipment in CSS units. It can also assess logistics improvements that add capacity by adding entire new CSS units.

LDM can assess the effect on combat performance of a variety of other changes, but the POLA methodology includes no means to estimate their costs. The simplest example is that of adding stocks of ammunition, war reserve equipment, or other resources. It should be easy to estimate the purchase price of the resources, but there will also be costs for storage facilities and maintenance services in peacetime. LDM can also assess the effects on combat performance of reducing the capacity to perform a logistics function. Again, estimating the resulting savings presents problems, as I discuss below.

LDM is not well suited to analyze improvements in command and control, even command and control of logistics functions. Nor will it analyze improvement in communications, intelligence, or (of course) weaponry. However, if such improvements can be represented in CEM or FORCEM, then their effects can be incorporated into LDM by recalibrating.

An analysis consists of the following steps:

- Define excursion cases that incorporate possible logistics improvements or reductions to the base case (this step will use the capacity models);
- Estimate the effects of each logistics improvement on combat performance measures, using LDM;
- Estimate the cost of each logistics improvement, using the cost model.

A genuine analysis would investigate many possible logistics improvements or reductions. By comparing their costs and effects on combat performance, one could arrive at a more balanced Army program, one that provides greater combat effectiveness for each logistics dollar spent. In the illustrative analysis below, however, I have se-

lected a single logistics improvement (and its corresponding reduction) to investigate.

DEFINING EXCURSION CASES

I distribute a test case with the LDM program, which I use here as the base case in an illustrative analysis. The ammunition distribution function in the test case does not match Fig. 3. Instead, ammunition must be handled at every echelon and can skip none. Frequently during the simulation, the ammunition-handling capacity at one particular echelon is exhausted, without meeting the full demand for ammunition. The capacity at that echelon is shown in Table 1, along with the number of divisions supported.

In the test case, the CSS units that provide the capacity are not identified. For this illustration, I will suppose that this capacity is supplied by 14 GS Ordnance Companies (SRC = 09488L000), one entering the simulation at the same time as each division. Each of the first ten companies, which are present at time zero, can handle 2160 tons of ammunition per day. Each of the next four companies, which enter the simulation at times of 24, 36, and 204 hours, can handle 1800 tons/day. According to the TOE for a GS Ordnance Company, the unit is designed to have a capacity of 3676 tons/day.

In a genuine analysis, I would obtain the capacities of CSS units in the base case by determining their equipment on hand in the base case from the TAEDP and applying a simple capacity model such as discussed earlier. Because no actual CSS units are identified for the test case, I reverse the process, in effect using a simple capacity model to design GS Ordnance Companies with the desired capacities.

Table 1
Ammunition-Handling Capacity over Time
in the Test Case

Time (hr)	Divisions Supported	Average Capacity	
		Total Capacity (tons/day)	per Division (tons/div-day)
0	10	21600	2160
24	12	25200	2100
36	13	27000	2077
204	14	28800	2057

For this illustration, I will suppose that the capacity of a GS Ordnance Company, SRC = 09488L000, is determined entirely by its inventories of forklifts and cranes. According to the TOE, this kind of unit requires five types of forklifts and a single type of crane, as shown in Table 2. For my capacity model, I assume that each critical equipment item contributes an amount to the unit's capacity that is proportional to its lift capability. That is, a forklift capable of lifting 50,000 lb will contribute 12.5 times more to the unit's capacity than a forklift that can lift only 4,000 lb.¹ The Req Qty column of Table 2 shows the inventories of the critical items required to give a GS Ordnance Company its full design capacity of 3676 tons/day, and the Req Lift column calculates that the lift capabilities of these items total to 272 tons. The next two pairs of columns show critical equipment inventories and lift capabilities of GS Ordnance Companies with approximately the reduced capacities I need for my base case.²

Table 3 shows the schedules for adding ammunition-handling capacity in the six cases I have selected to use in this illustrative analysis. Starting from the base case (Case 4), I increase ammunition-handling capacity by raising successively more GS Ordnance Companies to their design capacities. The companies are improved in the order in which they enter the base case, the first unit to enter being the first unit improved. I extend this sequence in the opposite direction by eliminating some of the GS Ordnance Companies from the base case. I eliminate them in the opposite order that they enter the base case, the last unit to enter in the base case being the first unit dropped.

ESTIMATING EFFECTS ON COMBAT PERFORMANCE

To estimate the effects on combat performance of these variations in ammunition-handling capacity, I construct six sets of input data files

¹This may well not be true. Cranes may accomplish fewer (or more) lifts per day than forklifts, and large forklifts may accomplish fewer (or more) lifts per day than small ones. Advice can be sought from the Training and Doctrine Command (TRADOC) school responsible for designing the TOE, in this case the Missile and Munitions Center and School at Redstone Arsenal, Alabama.

²Some types of ammunition (e.g., the Multiple Launch Rocket System (MLRS)) or ammunition in some configurations (e.g., containerized) may require particular equipment items for their handling. This suggests that there are several measures of capacity, rather than the single one (tons per day) that I have adopted. However, I have tried to maintain equipment with different lift capacities in roughly the same proportions in all three versions of the GS Ordnance Company. This should help maintain all measures of capacity in a constant relation, making my single measure of capacity a good indicator for all the types of capacity provided by the actual unit.

Table 2
Critical Equipment Items for the GS Ordnance Company

Line Item Number (LIN)	Nomenclature	Req Qty	Req Lift (tons)	2160 Qty	2160 Lift (tons)	1800 Qty	1800 Lift (tons)
T48941	Truck Lift Fork: Dsd 50000 lb cont	4	100	2	50	2	50
T49255	Truck Lift Fork: Dsl drv'n 4000 lb	4	8	4	8	2	4
X50900	Truck Lift Fork: Elec 6000 lb 180	2	6	2	6	1	3
X48914	Truck Lift Fork: Dsl drv'n 6000 lb	10	30	10	30	4	12
X50489	Truck Lift Fork: Elec 4000 lb 180	4	8	3	6	2	4
F39378	Crane Wheel MTD: 20 ton w/boom	6	120	3	60	3	60
	Total lift (tons)		272		160		133
	Capacity (proportional to total lift)		3676		2162		1797

Table 3
**Ammunition-Handling Capacities over Time
for Six Cases in the Illustrative Analysis
(tons/day)**

Time (hr)	Unit No.	(Base)					
		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
0	1	0	2160	2160	2160	3676	3676
0	2	0	2160	2160	2160	3676	3676
0	3	0	2160	2160	2160	3676	3676
0	4	0	2160	2160	2160	3676	3676
0	5	0	0	2160	2160	3676	3676
0	6	0	0	2160	2160	3676	3676
0	7	0	0	2160	2160	3676	3676
0	8	0	0	2160	2160	2160	3676
0	9	0	0	0	2160	2160	3676
0	10	0	0	0	2160	2160	3676
24	11	0	0	0	1800	1800	3676
24	12	0	0	0	1800	1800	3676
36	13	0	0	0	1800	1800	3676
204	14	0	0	0	1800	1800	3676
	Total	0	8640	17280	28800	39412	51464

for the Logistics Decision Model described above. The cases differ only in the amount of ammunition-handling capacity added at each time period. Figure 4 shows example results from the six cases.

Blue ammunition consumption depends strongly on ammunition-handling capacity. It is the same for the first two days of all cases, as the divisions exhaust most of their basic ammunition loads. Thereafter, the less the ammunition-handling capacity, the less ammunition is supplied to the divisions and the less they can consume. However, even in Case 1, with an ammunition-handling capacity of zero, the divisions do not entirely cease to expend ammunition in the ten days of the simulation, for they ration their ammunition by arming and sending into combat only a fraction of their artillery, tanks, and other weapon systems.

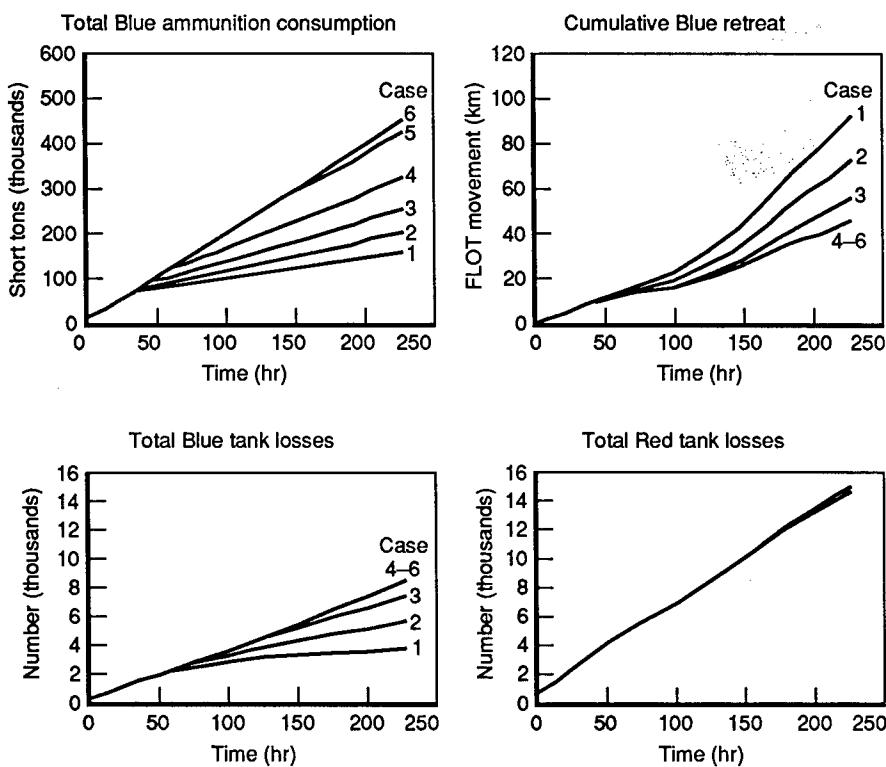


Fig. 4—Results from the Six Analysis Cases

Neither the cumulative distance that Blue retreats nor the total Blue tank losses is affected by increases in ammunition-handling capacity above the base case (Case 4). This suggests that such increases are of little value. However, decreases will cause Blue to lose ground to Red. At the same time, decreases in ammunition-handling capacity cause Blue to withhold weapons from combat and, therefore, to suffer fewer losses. The user must decide whether loss of territory outweighs the decrease in attrition.

Interestingly, the changes in Blue ammunition-handling capacity, and the consequent changes in ammunition expenditures by Blue, have no significant effect on the number of Red tanks lost. The LDM estimates that in the face of lessened (or heightened) opposition, Red becomes more (or less) aggressive. Rather than defending, a higher (or lower) fraction of Red forces attacks the Blue forces opposing them locally. This enables Red to gain (or lose) ground, but it maintains Red's loss rate roughly constant.

ESTIMATING COSTS OF LOGISTICS CHANGES

Four logistics changes to individual GS Ordnance Companies occur in the six cases. Two changes lead to increases in capacity, from 1800 tons/day or 2160 tons/day to 3676 tons/day. The other two changes are the elimination of units with capacities of 1800 tons/day or 2160 tons/day. To estimate the costs of these changes, I first estimate the costs of creating and maintaining three different units—units with capacities of 3676, 2160, and 1800 tons/day.

Table 4 shows the inputs and outputs of the cost model for these three units. The units all have the same personnel inventories and the same inventories of noncritical equipment items, namely the full wartime requirement from the TOE. Inventories of the critical items can be found in Table 2. Prices of equipment items can be found in the Army Master Data File, as can the Appropriation category, which provides funds for procuring each equipment item. The only outputs I have shown are the total nonrecurring and annual recurring costs. The cost model breaks these costs out in many subcategories.

The cost of changing a unit from a capacity of 1800 tons/day or 2160 tons/day to one of 3676 tons/day is the difference between the costs of creating and maintaining the units at the two different capacities. The differences in the nonrecurring costs will be incurred in the year or years in which the added forklifts and cranes are budgeted for.

Table 4**Cost Model Inputs and Outputs for GS Ordnance Companies with Different Capacities**

Input	Capacities (tons/day)		
	3676	2160	1800
Procurement of unit equipment, \$ million			
Aircraft procurement (Appn ^a 2031)	0.	0.	0.
Missile procurement (Appn 2032)	0.236	0.236	0.236
WTCV procurement (Appn 2033)	0.174	0.174	0.174
Other equipment procurement (Appn 2035)	4.582	4.253	3.98
Personnel			
Officers + warrant officers	9	9	9
Enlisted personnel	233	233	233
Output			
Nonrecurring cost (\$ millions)	11.474	11.085	10.761
Annual recurring cost (\$ million/year)	10.904	10.872	10.845

^aAppropriation category.

The differences in the annual recurring costs will be incurred in the year the new equipment is delivered and in every year thereafter until the equipment is discarded.

It is straightforward, therefore, to calculate the nonrecurring and annual recurring costs for the excursion cases that add capacity (Cases 5 and 6). In Case 5 (see Table 3), seven units are improved from capacities of 2160 tons/day to 3676 tons/day, so the incremental costs are seven times the corresponding differences from Table 4. The costs for Case 6 are calculated similarly.

The savings resulting from eliminating a unit are problematic. One cannot recover the nonrecurring cost, but depending on what one does with the unit's original resources, one may avoid some or all of the annual recurring cost. Only if the personnel leave the Army and the equipment is discarded can the entire recurring cost be saved. If the equipment is discarded but the personnel are retained, the net annual saving drops to less than one-half million dollars per unit eliminated. And if the equipment is retained as well as the personnel, there may be no savings at all.

If the Army retains some of these resources, it must be presumed that they will derive some benefit from them. I have assumed this benefit does not take the form of ammunition-handling capacity, so it does not appear in the illustrative example. To make the analysis complete, therefore, it would be necessary to specify the disposition of

personnel and equipment from the eliminated units and to estimate their costs and benefits in their new roles.

Figure 5 shows the nonrecurring and annual recurring costs of the six cases, plotted against the total ammunition-handling capacity. Nonrecurring costs can be given for all six cases (they are zero for the base case and for the cases that eliminate units). For the reasons discussed above, annual recurring costs cannot be given for the three cases that eliminate units.

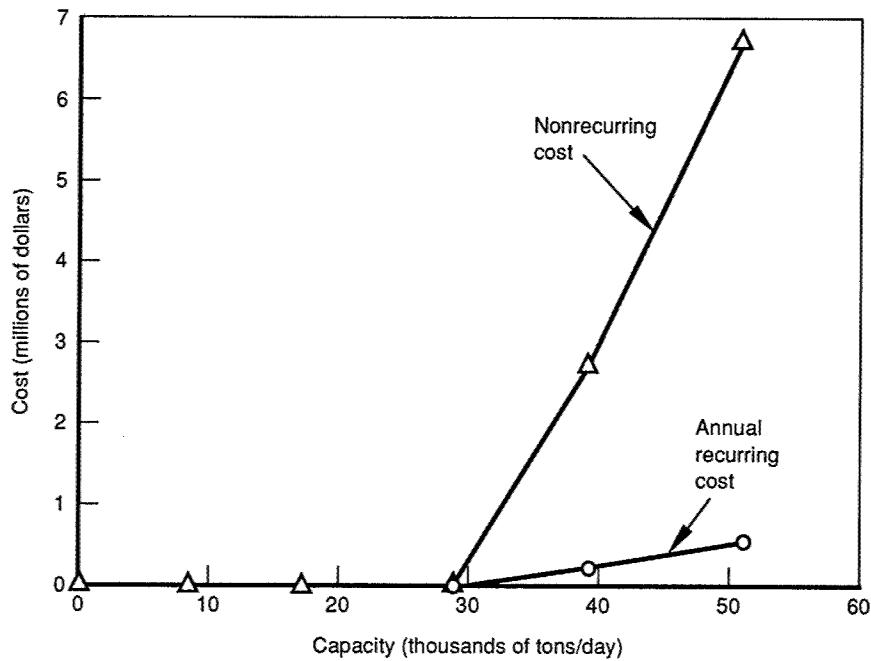


Fig. 5—Cost Versus Capacity for the Six Analysis Cases

5. LOGISTICS NET ASSESSMENT (LNA)

The methodology developed by the POLA project has been adopted by the U.S. Army Logistics Evaluation Agency (LEA). The Operations Research and Systems Analysis (ORSA) Support Team at LEA is responsible for further development and implementation of methodology, for maintaining data files, and for periodically recalibrating LDM and providing it to action officers in the Pentagon. They have created a *Logistics Net Assessment* system that consists of:

- An input processor, written as a dBase III application;
- The LDM program;
- An output analyzer, in the form of Lotus 1-2-3 spreadsheets with macros;
- A graph generator, which uses Lotus Graph Writer.

These modules are integrated through the use of DOS batch files. The LNA system is documented in the LNA User's Guide [6]. Users interested in obtaining the entire LNA system should contact the ORSA Support Team at LEA.

As of this writing, the LNA package does not include the cost model. However, the ORSA Support Team intends to add it to the package in the near future.

The ORSA Support Team has the capability and the responsibility to:

- Periodically recalibrate LDM and set up a new base case (including a theater support representation and inventories of CSS units entering the theater over time);
- Extract data from standard Army files (FAS, TAEDP, etc.) to make construction of the standard kinds of excursion cases simple;
- Put all this together in the LNA package and send it to action officers in the Pentagon.

Each action officer performs his own mini-analyses for the resources he is responsible for. The ORSA Support Team can perform its own more complete analyses.

REFERENCES

1. Bigelow, J. H., *Performance-Oriented Logistics Assessment (POLA): Users' Manual for the Logistics Decision Model (LDM), Version IV*, RAND, R-3814-A, 1992.
2. Bigelow, J. H., T. Martin, and R. L. Petruschell, *Performance-Oriented Logistics Assessment (POLA): Preparing the Logistics Decision Model (LDM) for Use in Analyses*, RAND, N-3965-A, 1992.
3. Bigelow, J. H., T. Martin, and R. L. Petruschell, *Performance-Oriented Logistics Assessment (POLA): Relating Logistics Functional Capacities to Resources and Costs*, RAND, N-3354-A, 1992.
4. AR 220-1, *Unit Status Reporting*, U.S. Army, September 1986.
5. FM 9-6, *Ammunition Service in the Theater of Operations*, U.S. Army, January 1984.
6. *Logistics Net Assessment System: System User's Guide*, ORSA Support Team, U.S. Army Logistics Evaluation Agency, New Cumberland, Pennsylvania 17070, 21 July 1989.